Inclusive η' production in B decays and the Enhancement due to charged technipions

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Abstract

The new contributions to the charmless B decay $B \to X_s \eta'$ from the unit-charged technipions $P^{\pm}$ and $P_8^{\pm}$ are estimated. The technipions can provide a large enhancement to the inclusive branching ratio: $Br(B \to X_s \eta') \sim 7 \times 10^{-4}$ for $m_{p1} = 100GeV$ and $m_{p8} = 250 \sim 350GeV$ when the effect of QCD gluon anomaly is also taken into account. The new physics effect is essential to interpret the CLEO data.

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Recently CLEO has reported [1] a very large branching ratio for the inclusive production of η':

$$Br(B \to \eta' X_s) = (6.2 \pm 1.6 \pm 1.3) \times 10^{-4}, \quad for \;\; 2.0 \leq E_{\eta'} \leq 2.7 GeV \tag{1}$$

and a corresponding large exclusive branching ratio [2]

$$Br(B^\pm \to \eta' K^\pm) = (7.1^{+2.5}_{-2.1} \pm 0.9) \times 10^{-5} \tag{2}$$

where the acceptance cut was used to reduce the background from events with charmed mesons. By using the Standard Model (SM) factorization one finds [3] $Br(B \to \eta' X_s) \sim (0.5 - 2.5) \times 10^{-4}$ including the experimental cut, with the largest yields corresponding to a fairly limited region of parameter space, which is much smaller than the observed inclusive rate in eq.(1).

Up to now a number of interpretations have been proposed [4, 5, 6, 7, 8, 3] to account for the observed large branching ratio of $B \to \eta' X_s$ and/or the exclusive branching fraction $Br(B^\pm \to \eta' K^\pm)$. These include: (a) conventional $b \to s q\bar{q}$ with constructive interference between the $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$ components of the η'[4], (b) $b \to c\bar{c}s$ decay enhanced $c\bar{c}$ content of the η' [5, 6], (c) $b \to sg^* \to sg\eta'$ from QCD gluon anomaly [7] or from both QCD gluon anomaly with running α_s and the new physics effects [8, 3], (d) non-spectator effects[9].

From the above works, the following major points about the inclusive and exclusive branching ratios $Br(B \to \eta' X_s)$ and $Br(B^\pm \to \eta' K^\pm)$ can be reached;

1. The SM factorization can, in principle, account for the exclusive η' yield without the need of new physics[3, 9]. Although a SM "cocktail" solution for large inclusive rate $Br(B \to \eta' X_s)$ involving contributions from several mechanisms is still possible, but the intervention of new physics in the form of enhanced chromo-magnetic dipole operators provides a simple and elegant solution to the puzzle in question[8, 3]. On the other hand, the short-distance $b \to \eta' sg$ subprocess most possibly does not affect the exclusive $B \to \eta' K$ branching ratios[3].

2. The observed inclusive branching fraction is larger than what is expected from scenario (a). Furthermore, the data show that the invariant mass spectrum $M(X_s)$ of the particles recoiling against the η' peaks above $2GeV$[1].

3. The large inclusive rate may be connected to the standard model QCD penguins via the gluon anomaly, which leads to the subprocess $b \to sg^* \to sg\eta'$. Taking a constant $gg\eta'$ vertex form factor $H(0, 0, m_{\eta'}^2)$ [7], the observed large branching ratio in eq.(1) can be achieved. But as argued by Hou and Tseng [8], if one considers the

running of α_s implicit in $H(0,0,m_{\eta'}^2)$, the result presented in ref.[7] will be reduced by roughly a factor of 3. In other words, the new physics effect is essential to interpret the observed large inclusive rate[8].

4. As pointed by Kagan and Petrov [3], the $m_{\eta'}^2/(q^2 - m_{\eta'}^2)$ dependence of the $gg\eta'$ coupling should be considered. Including this dependence nominally reduce the former result [7] to $\sim 1.6 \times 10^{-5}$ including the cut, which is significantly smaller than the observed inclusive rate. This fact will strengthen the need for new physics.

5. It is possible to enhance the chromo-dipole bsg coupling by new physics at the TeV scale without jeopardizing the electrodipole $bs\gamma$ coupling[10, 11]. One explicit example in the framework of the Minimal Supersymmetric Standard Model (MSSM) has been studied in ref.[11].

In this letter we will show that the unit-charged technipions $P^{\pm}$ and $P_8^{\pm}$ appeared in almost all nonminimal technicolor models [12, 13] can provide the required enhancement to account for the observed large rate $Br(B \to \eta' X_s)$[1].

In the framework of the SM, the loop induced effective bsg coupling was calculated long time ago[14],

$$\Gamma_\mu^{SM} = g_s \frac{G_F}{4\sqrt{2}\pi^2} V_{is}^* V_{ib} \bar{s} T^a \left[F_1^i (q^2 \gamma_\mu - q_\mu \not{q}) - i\, F_2^i \sigma_{\mu\nu} q^\nu (m_s L + m_b R) \right] b \tag{3}$$

where the g_s is the strong coupling constant, V is the CKM matrix, $T^a = \lambda^a/2$ and λ^a is the Gell-Mann matrix, $q = p_b - p_s$ and the charge radius form factors F_1^i and the dipole moment F_2^i ($i = u, c, t$) are

$$F_1^i = \frac{x_i}{12}\left[y_i + 13 y_i^2 - 6 y_i^3 \right] + \left[\frac{2y_i}{3} - \frac{x_i}{6}(4y_i^2 + 5y_i^3 - 3y_i^4) \right] \ln[x_i], \tag{4}$$

$$F_2^i = -\frac{x_i}{4}\left[-y_i + 3y_i^2 + 6y_i^3 \right] + \frac{3x_i^2 y_i^3}{2} \ln[x_i] \tag{5}$$

where $x_i = m_i^2/M_W^2$ and $y_i = 1/(x_i - 1)$ for $i = u, c, t$.

In the framework of Technicolor theory, the new effective bsg coupling can be derived by replacing the internal W-lines in the one-loop diagrams that induce bsg coupling in the SM with the charged technipion lines. Using the gauge and effective Yukawa couplings as given in refs.[12], one finds the new effective bsg coupling induced by $P^{\pm}$ and $P_8^{\pm}$,

$$\Gamma_\mu^{New} = g_s \frac{G_F}{4\sqrt{2}\pi^2} V_{is}^* V_{ib} \bar{s} T^a \left[F_1^{(i,New)} (q^2 \gamma_\mu - q_\mu \not{q}) - i\, F_2^{(i,New)} \sigma_{\mu\nu} q^\nu (m_s L + m_b R) \right] b \tag{6}$$

with

$$F_1^{New}(\xi_i,\eta_i) = \frac{D'(\xi_i)}{3\sqrt{2}G_F F_\pi^2} + \frac{8D'(\eta_i)}{3\sqrt{2}G_F F_\pi^2} \tag{7}$$

$$F_2^{New}(\xi_i,\eta_i) = -\left[\frac{D(\xi_i)}{3\sqrt{2}G_F F_\pi^2} + \frac{8D(\eta_i)+E(\eta_i)}{3\sqrt{2}G_F F_\pi^2}\right] \tag{8}$$

and

$$D(\xi) = \frac{-5+19\xi-20\xi^2}{24(1-\xi)^3} + \frac{4\xi^2-2\xi^3}{4(1-\xi)^4}\ln[\xi] \tag{9}$$

$$D'(\xi) = \frac{7-29\xi+16\xi^2}{72(1-\xi)^3} - \frac{3\xi^2-2\xi^3}{12(1-\xi)^4}\ln[\xi] \tag{10}$$

$$E(\eta) = \frac{12-15\eta-5\eta^2}{8(1-\eta)^3} + \frac{9\eta-18\eta^2}{4(1-\eta)^4}\ln[\eta] \tag{11}$$

where $\xi = m_{p1}^2/m_t^2$ and $\eta = m_{P8}^2/m_t^2$, and m_{p1} and m_{p8} denote the masses of the color-singlet and color-octet technipion $P^\pm$ and $P_8^\pm$ respectively. The technipion decay constant $F_\pi = 123GeV$ in the One-Generation Technicolor Model (OGTM) [12]. The G_F is the Fermi coupling constant $G_F = 1.16639 \times 10^{-5}(GeV)^{-2}$.

Comparing the effective bsg coupling Γ_μ^{New} in eq.(6) with the Γ_μ^{SM} in eq.(3), one can see that the form factors $F_1^{(i,New)}$ and $F_2^{(i,New)}$ are the counterparts of the F_1^i and F_2^i in the SM. The new form factors $F_1^{(i,New)}$ and $F_2^{(i,New)}$ describe the contributions to the decay $b \to sg$ from the charged technipions $P^\pm$ and $P_8^\pm$.

In the numerical calculation we use the branching ratio formula for $B \to \eta' + X_s$ with gluon anomaly as given in ref.[8],

$$\frac{d^2Br(b\to\eta' sg)}{dxdy} = 0.2\left[\frac{g_s(m_b)}{4\pi^2}\right]^2 \frac{a_g^2 m_b^2}{4}\left[|\Delta F_1|^2 c_0 + Re(\Delta F_1 F_2^*)\frac{c_1}{y} + |F_2|^2\frac{c_2}{y^2}\right] \tag{12}$$

where 0.2 comes from $(V_{cb}^2 G_F^2 m_b^2)/(192\pi^3) \simeq 0.2\Gamma_B$ via the standard trick of relating to $B_{s.l}$ (see ref.[7]). The factors c_0, c_1 and c_2 in eq.(12) are

$$\begin{aligned} c_0 &= \left[-2x^2y + (1-y)(y-x')(2x+y-x')\right]/2, \\ c_1 &= -(1-y)(y-x')^2, \\ c_2 &= \left[2x^2y^2 - (1-y)(y-x')(2xy-y+x')\right]/2 \end{aligned} \tag{13}$$

where $x = m^2/m_b^2$ with m is the physical recoil mass against the η' mason, and $y = q^2/m_b^2$ with $q = p_b - p_s$ and $x' = m_{\eta'}^2/m_b^2$. The term ΔF_1 was defined as $\Delta F_1 = F_1(x_t) - F_1(x_c)$. The factor $a_g = \sqrt{N_f}\alpha_s(\mu)/(\pi f_{\eta'})$ is the effective anomaly coupling $H(q^2, k^2, m_{\eta'}^2)$

as defined in ref.[7] and $f_{\eta'} = 131MeV$. For the running of α_s, we use the two-loop approximation as given for instance in ref.[15].

The Fig.1 shows the mass dependence of form factors in the SM and in the OGTM. The dot-dashed line corresponds to the $\Delta F_1 = -5.25$ in the SM, while the long dashed line shows the $\Delta F_1^{New} = F_1^{New}(\xi_t, \eta_t) - F_1^{New}(\xi_c, \eta_c) \approx -4.6$ in the OGTM, assuming $m_{p1} = 100GeV$ and $m_{p8} = 250 - 600GeV$. The short-dashed line is the $F_2 = 0.2$ in the SM for $m_t = 180GeV$ and $m_W = 80.2GeV$, while the solid curve is the F_2^{New} in the OGTM, assuming $m_{p1} = 100GeV$ and $m_{p8} = 250 - 600GeV$. It is easy to see that the size of F_2^{New} can be much larger than the F_2 in the SM for light color-octet technipion. Furthermore, the $P_8^{\pm}$ dominates the total contribution to the F_1^{New} and F_2^{New}.

Because we do not know the "correct" form of $gg\eta'$ vertex form factor $H(q^2, k^2, m_{\eta'}^2)$, we consider the following two different cases respectively.

Case-1: We consider the effect due to the running of α_s [8] as well as the new contribution from the charged technipions.

After the inclusion of the running of α_s one finds $Br(B \to \eta' X_s) \approx 3.4 \times 10^{-4}$ including the cut, as shown in Fig.2 (the dot-dashed line). The horizontal band in Fig.2 represents the CLEO data in eq.(1). The long dashed curve corresponds to the total inclusive branching ratio $Br(B \to \eta' X_s)$ when the new physics effects are also included. Numerically, $Br(B \to \eta' X_s) = (48.9 - 5.7) \times 10^{-4}$ for $m_{p1} = 100GeV$ and $m_{p8} = (250 - 600)GeV$. The theoretical prediction is now well consistent with the CLEO data for $m_{p8} \geq 350GeV$. The color-octet technipion $P_8^{\pm}$ dominates the total new contribution: the increase due to the $P^{\pm}$ is only about 10% at the level of the corresponding branching ratio.

Case-2: We consider the effect of the $m_{\eta'}^2/(q^2 - m_{\eta'}^2)$ suppression and the new physics contribution from $P^{\pm}$ and $P_8^{\pm}$.

When the new suppression factor $m_{\eta'}^2/(q^2 - m_{\eta'}^2)$ is taken into account one finds $Br(B \to \eta' X_s) = 2.3 \times 10^{-5}$ including the cut as shown by the short dashed line in Fig.2, which is much smaller than the CLEO measurement. When the new contributions from the charged technipions are included, the inclusive branching ratio $Br(B \to \eta' X_s)$ can be enhanced greatly as illustrated by the solid curve in Fig.2. Numerically, $Br(B \to \eta' X_s) = (15.2 - 0.7) \times 10^{-4}$ for $m_{p1} = 100GeV$ and $m_{p8} = (250 - 600)GeV$. The theoretical prediction is now consistent with the CLEO data for $m_{p8} \sim 280GeV$. The new physics effect is essential to interpret the CLEO data for the Case-2. Again, the color-octet technipion $P_8^{\pm}$ dominates the total contribution as that in Case-1.

In this letter we show a real example that the observed large ratio $Br(B \to \eta' X_s)$ can be explained by the new physics contributions from the unit-charged technipions $P^{\pm}$ and $P_8^{\pm}$. Because the major properties of the technipions in different technicolor models

are generally very similar, the analytical and numerical results obtained in this letter are representative and can be extended to other new technicolor models easily.

In this letter, we firstly evaluate the new one-loop penguin diagrams with the internal $P^{\pm}$ and $P_8^{\pm}$ lines and obtained the new form factors $F_1^{New}(\xi_i, \eta_i)$ and $F_2^{New}(\xi_i, \eta_i)$ which describe the new physics contributions to the decay in question. The size of F_2^{New} can be rather large for relatively light charged technipions. Secondly, we combine the new form factors F_i^{New} (i =1,2) with their counterpart F_1 and F_2 in the SM properly and use them in the numerical calculation. We finally calculate the inclusive branching ratios for both Case-1 and Case-2. As illustrated in Fig.2, the unit-charged technipions can provide a large enhancement to account for the large rate $Br(B \to \eta' X_s)$ observed by CLEO[1].

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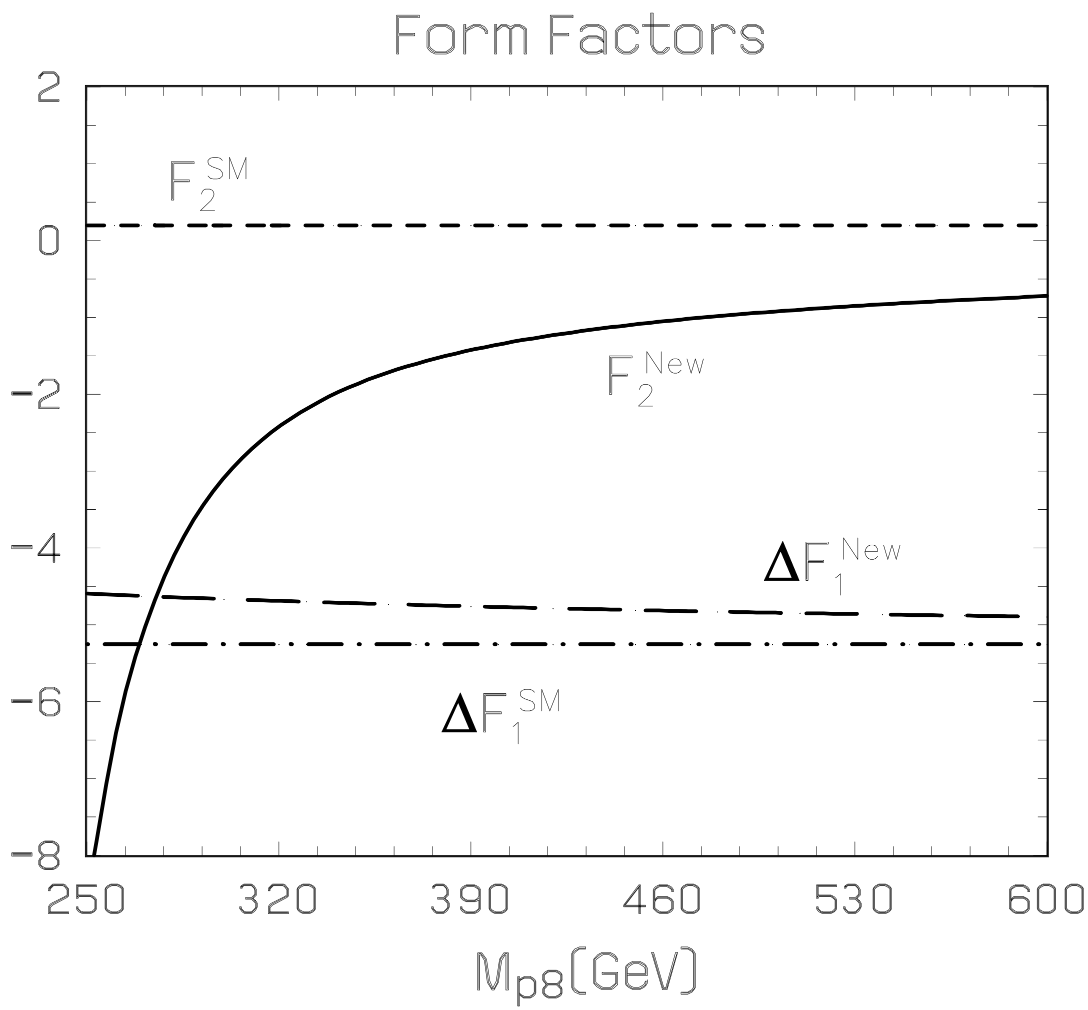
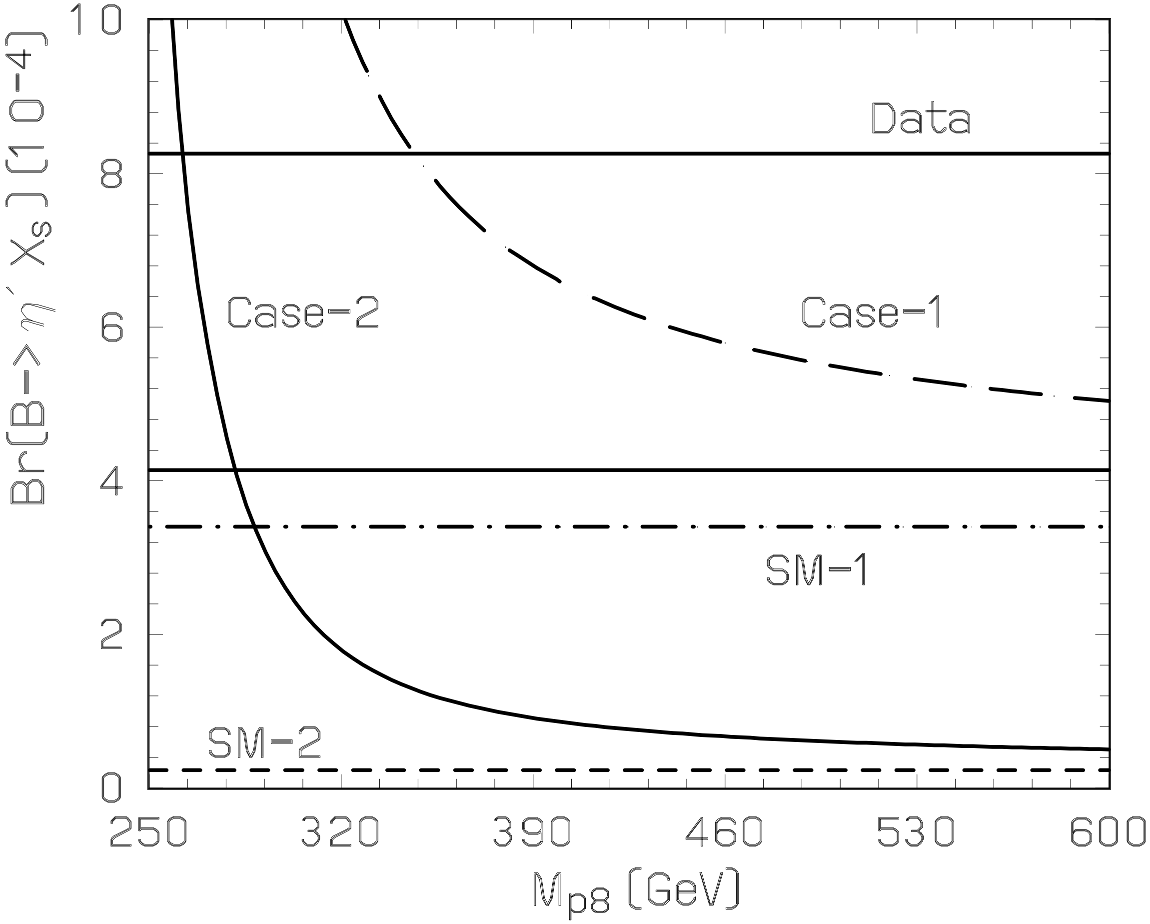
Figure Captions

Fig.1: The dot-dashed line shows $\Delta F_1 = -5.25$ in the SM, the long dashed line corresponds to the ΔF_1^{New}, the short dashed line is the $F_2^{SM} = 0.2$ and the solid curve is the F_2^{New} induced by unit-charged technipions.

Fig.2: The horizontal solid band represents the CLEO data $Br(B \to \eta' X_s) = (6.3 \pm 2.1) \times 10^{-4}$. The dot-dashed (short dashed) line is the SM prediction in Case-1 (Case-2), while the long-dashed and solid line show the total inclusive branching ratio $Br(B \to \eta' X_s)$ when the new physics effects are included in Case-1 and Case-2, respectively.


Form Factors
2
0
-2
-4
-6
-8
250
320
390
460
530
600
M_{p8}(GeV)
F_2^{SM}
F_2^{New}
ΔF_1^{New}
ΔF_1^{SM}



Data
Case-2
Case-1
SM-1
SM-2
Br(B-> η′ X_s) (1 0-4)
10
8
6
4
2
0
250
320
390
460
530
600
M_p8 (GeV)